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PREDICTION OF SUMMER RAINFALL AND TEMPERATURE FOR ENGLAND AND WALES FROM ANOMALOUS ATMOSPHERIC CIRCULATION IN SPRING

By R. MURRAY

Summary. From an analysis of 97 years of monthly mean pressure anomaly data for March, April and May, simple indices of anomalous circulation in key areas of the northern hemisphere are related to the subsequent general rainfall and mean temperature in the summer over England and Wales. Useful predictors are shown to be in evidence on about 50 per cent of occasions in early spring. On the basis of anomalous circulation in March, April and May, objective predictors can be applied on most occasions with considerable success.

Introduction. This paper presents objective procedures for predicting summer rainfall and mean temperature, derived from analysing mean monthly pressure anomalies over the northern hemisphere in March, April and May. The general method of attacking the seasonal prediction problem has been given in some detail in a recent paper by Murray[1] dealing with winter. In the present paper the general rainfall over England and Wales and Manley's[2] central-England mean temperature are employed. The percentile boundaries used for rainfall and temperature have already been published by Murray.[3,4]

It is convenient here to repeat briefly some of the discussion on procedure which is given in the earlier paper by Murray.[1] For each class of summer, as specified by the quintile of mean temperature in central England, the mean pressure anomaly maps in March, April and May preceding the specified summers were computed. These composite mean pressure anomaly maps in the spring months generally show areas where the pressure anomalies are apparently significantly different from zero (at the 5 per cent level), as indicated by the *t*-test. For example, Figure 1 shows the composite mean pressure anomaly map for Mays before very cool (T_1 or quintile 1) summers. It appears that mean pressure anomalies are significantly positive in the polar region and over north Africa. Incidentally, a composite map for Mays before very warm (T_5 or quintile 5) summers shows apparently significant negative pressure anomalies over the Arctic of western Canada and also over south Spain and Morocco. In other words for the opposite type of summer the significant mean pressure anomalies in May have different signs but are located in roughly the same areas as shown in Figure 1. Composite maps like Figure 1 suggest that the circulation in certain areas in March, April

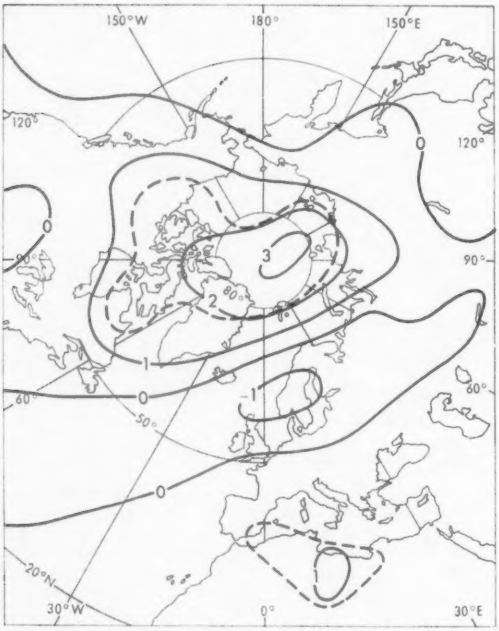

FIGURE 1—COMPOSITE MEAN PRESSURE ANOMALY PATTERN FOR MAY PRECEDING VERY COOL (QUINTILE 1) SUMMERS OVER CENTRAL ENGLAND

Pressure anomalies (1-mb intervals) from 1873–1968 average. Broken lines enclose areas where anomalies are significantly different from zero at the 5 per cent level according to *t*-test.

and May might well be associated in a complex way with the development of characteristic temperature quintiles in the following summer. To explore this further the mean monthly pressure anomalies at one or occasionally more than one grid point within areas where the mean anomalies on the composite maps were apparently significant were then computed for the particular spring month in question for each month from 1873. These monthly mean pressure anomalies were ranked and related to the temperature quintiles of the summers following. In many cases the difference between monthly mean pressure anomalies at two grid points was computed and ranked when it was thought from examining the composite mean pressure anomaly map that the anomaly in the pressure gradient might be a more relevant indicator of abnormal circulation. In a few cases grid points were taken where the composite mean pressure anomaly was not significant at the 5 per cent level, particularly when pressure anomaly gradients seemed likely to be informative. The broad association between monthly mean pressure anomaly data and summer temperature (quintiles) was readily seen from contingency tables. The significance of such tables cannot be obtained by merely computing the chi-square statistic since the number of degrees of freedom is uncertain in these cases. However, the chi-square statistic still indicates roughly the relative importance of the associations. As indicated in the earlier paper,

it was found best to examine the ranked pressure anomaly data and to classify objectively according to the following criteria :

(a) The class must contain at least 15 years.

(b) If both ends of the distribution of pressure data appear to have an association with summer temperature then the Sutcliffe score *(SS)* for each class must be equal to or greater than 1·2.

(c) If only one end of the distribution of pressure data appears to have an association with summer temperature then $SS \geqslant 1{\cdot}4$.

(d) The pressure class was taken so that the critical pressure anomaly boundary was a whole number (e.g. pressure anomaly > 3·0 mb) provided also that (a) and either (b) or (c) were also satisfied.

Details concerning the Sutcliffe score are given in the earlier paper by Murray.[1]

The same general procedure was carried out in searching for predictors of summer rainfall except that terciles of rainfall were employed and also the upper and lower ten-percentiles.

In cases when pressure anomalies (or differences) were at nearby places and clearly represented the same features of the large-scale anomaly of circulation, one was usually selected. As far as can be seen little difference would have resulted in the conclusions if other choices had been made in such cases.

Forecasting summer rainfall. Predictive indications given by simple indices of anomalous monthly mean circulation in the three spring months are summarized in Table I, in which latitude/longitude positions are abbreviated (e.g. 55 10 is 55°N 10°W and 55 10E is 55°N 10°E).

TABLE I—PRESSURE ANOMALIES AND PRESSURE ANOMALY DIFFERENCE AT KEY AREAS IN MARCH, APRIL AND MAY RELATED TO SUMMER RAINFALL IN ENGLAND AND WALES

Rule No.	Pressure anomaly (PA) or difference	Normal	Critical anomaly	Rainfall (terciles)		
		millibars		1	2	3
(a) March						
1	PA(70 100E) − PA(60 170E)	1018·0 − 1011·4	< 0·0	5	19	19
2	PA(70 100E) − PA(60 170E)	1018·0 − 1011·4	> 3·0	25	6	10
3	PA(50 110) − PA(60 170E)	1017·6 − 1011·4	> 6·0	10	5	3
4	PA(55 170E)	1007·3	< −1·0	25	10	10
5	PA(55 170E)	1007·3	> 2·0	2	14	12
6	PA(65 30E) − PA(75 100E)	1011·0 − 1017·0	> 7·0	13	4	5
7	PA(70 60) − PA(65 90E)	1011·8 − 1018·7	< −7·0	8	5	2
(b) April						
8	PA(40 20E) − PA(60 20)	1012·9 − 1009·1	< −4·0	5	5	14
9	PA(40 20E) − PA(60 20)	1012·9 − 1009·1	> 3·0	12	8	2
10	PA(55 70) − PA(60 150)	1014·8 − 1009·4	< −5·0	2	8	8
11	PA(55 70) − PA(60 150)	1014·8 − 1009·4	> 4·0	12	4	4
12	PA(80 00)	1017·2	> 5·0	2	5	10
13	PA(55 20E)	1013·5	< −2·0	3	5	12
14	PA(80 00) − PA(55 20E)	1017·2 − 1013·5	< −7·0	8	5	3
15	PA(80 00) − PA(55 20E)	1017·2 − 1013·5	> 4·0	6	7	15
(c) May						
16	PA(70 60E) − PA(60 00)	1014·0 − 1014·6	> 6·0	10	4	2
17	PA(70 80)	1018·0	≥ 3·0	3	4	10
18	PA(70 80) − PA(55 180)	1018·0 − 1008·9	> 4·0	4	3	12

Normal monthly pressure or pressure difference refers to the period 1873 to 1968.

Note : Tercile boundaries, based on period 1874 to 1963, are: $R_1 < 193$ mm; $193 < R_2 < 254$ mm; $R_3 > 254$ mm.

For convenience the positions of PA and PA differences employed in Table I are shown in Figures 2, 3 and 4 for each month. In Figure 2 it is clear that anomalously high or low pressure in the Bering Sea and near the Taymyr Peninsula in northern Siberia are especially important as predictors in March. Figure 3 shows that abnormal pressure differences from the Gulf of Alaska to eastern Canada, from off north-east Greenland to the southern Baltic and from south of Iceland to near the west coast of Greece are likely to be useful as predictors in April. Judging by the number of predictors shown in Table I it appears that the circulation in May is less important than in March and April in setting the stage for the rainfall in summer.

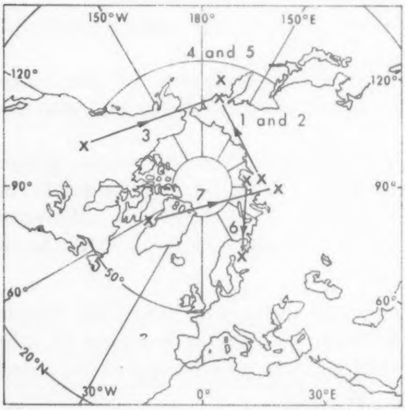

FIGURE 2 — POSITIONS OF SUMMER RAINFALL PREDICTORS BASED ON MARCH MEAN PRESSURE ANOMALIES GIVEN IN TABLE I (a)

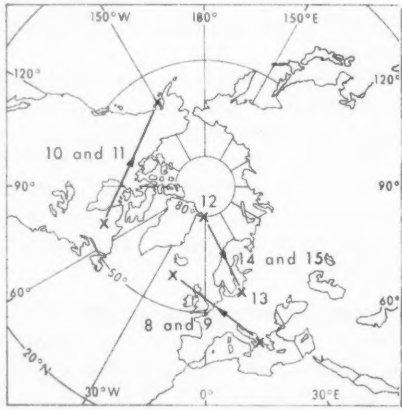

FIGURE 3 — POSITIONS OF SUMMER RAINFALL PREDICTORS BASED ON APRIL MEAN PRESSURE ANOMALIES GIVEN IN TABLE I (b)

Positions used in PA differences are joined by arrows.

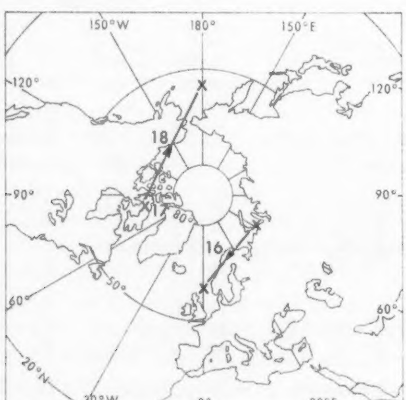

FIGURE 4—POSITIONS OF SUMMER RAINFALL PREDICTORS BASED ON MAY MEAN PRESSURE ANOMALIES GIVEN IN TABLE I (c)

Positions used in PA differences are joined by arrows.

The individual rules given in Table I are not all satisfied in general in a particular year, nor do they always indicate the same type of summer rainfall when the pressure criteria are satisfied. In the paper on predicting winter rainfall several possible discriminant procedures were mentioned but a very simple method of combining the individual rules was adopted with considerable success. The same simple procedure is employed in the present paper. Equal weight was given to each of the basic rules listed in Table I and simple, common-sense relationships between the number of individual rules which predict dry *(N_d)* and wet *(N_w)* summers and the occurrence of different classes of summer were developed as shown in Table II.

TABLE II—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED ON MONTHLY PRESSURE ANOMALIES IN MARCH, APRIL AND MAY OVER THE NORTHERN HEMISPHERE AND SUMMER RAINFALL OVER ENGLAND AND WALES

Period		Predictor $N_d - N_w$	Winter rainfall (terciles) 1	2	3	Totals	*SS*
(a) March		$\geqslant 3$	16	3	2	21	2·6
		$\leqslant -1$	2	11	15	28	1·8
(b) April		$\geqslant 1$	17	11	3	31	1·8
		$\leqslant -3$	1	6	13	20	2·4
(c) May		$\geqslant 0$	10	4	1	15	2·4
		$\leqslant -1$	4	4	16	24	2·0
(d) March + April		$\geqslant 1$	28	9	7	44	1·9
		($\geqslant 3$)	(17)	(2)	(1)	(20)	(3·2)
		$\leqslant -1$	6	16	23	43	1·7
		($\leqslant -3$)	(0)	(4)	(11)	(15)	(2·9)
(e) March + April + May	1	$\geqslant 2$	23	5	3	31	2·6
		($\geqslant 4$)	(15)	(0)	(1)	(16)	(3·5)
	2	1, 0 or −1	9	16	8	33	0·9
	3	$\leqslant -2$	2	10	21	33	2·3
		($\leqslant -4$)	(0)	(4)	(12)	(16)	(3·0)

N_d and N_w are the number of individual rules (see Table I) which indicate dry (tercile 1) and wet (tercile 3) summers respectively. *SS* is the mean Sutcliffe score. Tercile boundaries are given in Table I.

Note : For a predictor value in brackets, the tercile distribution is shown in brackets.

Table II contains predictive relationships based on the various individual monthly rules. Two useful predictors are available at the end of March but these are applicable on only about 50 per cent of occasions. When the April pressure anomaly information becomes available rules based on April only or on March and April together can be applied. The combined March and April predictors are likely to be usable on over 85 per cent of occasions and should generally take precedence over the March indications when there is a difference in their predictions. May adds further useful information on occasions. By the end of May, rules (e)1 to (e)3 based on the three spring months come into operation; these rules cover all cases, but (e)1 and (e)3 are more significant than (e)2. When more stringent conditions are set, as shown in brackets in Table II, very strong predictive relationships are in evidence. For instance, in rule (e)1 when $N_d - N_w \geqslant 4$ in March, April and May then only one wet summer occurred in 16 years; in rule (e)3 when $N_d - N_w \leqslant -4$ no dry summer occurred in 16 years. It is interesting to see in Figure 5 the composite mean pressure anomaly pattern in summer for the group of years in which the predictor in spring satisfied the criterion $N_d - N_w \geqslant 4$ (Table II, rule (e)1). The mean pressure in Figure 5 is

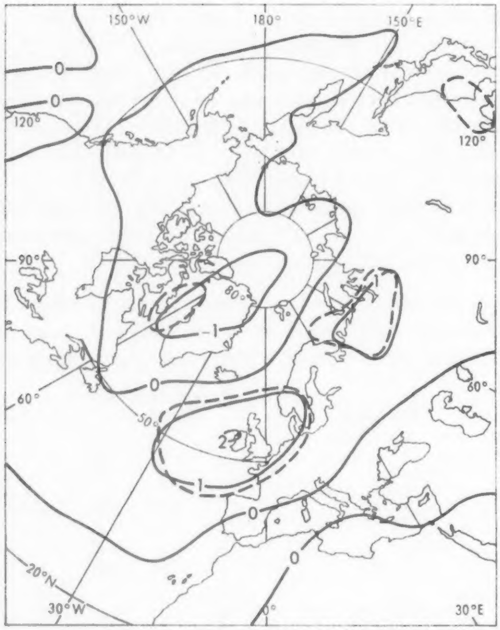

FIGURE 5—COMPOSITE MEAN PRESSURE ANOMALY PATTERN IN SUMMERS FOLLOWING SPRINGS SATISFYING RAINFALL PREDICTOR $N_d - N_w \geqslant 4$ GIVEN IN TABLE II (e) 1

See notes under Figure 1.

significantly (at the 5 per cent level) above average over and near the British Isles and also in north Russia, and below average in west Greenland. For the less restrictive criterion $N_d - N_w \geqslant 2$ the composite map (not shown) is a weaker version of Figure 5. In the case of the group of summers associated with the predictor $N_d - N_w \leqslant -4$ (Table II, rule (e)3), the mean pressure anomaly over and near the British Isles is significantly (at the 5 per cent level) below average and it is not surprising that most of these summers are wet. In this case the mean pressure is also significantly above average in central Asia at about 45°N 80°E and almost significantly above average in the Canadian Arctic. The composite map for the $N_d - N_w \leqslant -4$ case depicts patterns which are quite similar to those in Figure 5 (case $N_d - N_w \geqslant 4$) but with the signs of the pressure anomalies reversed.

It is believed that the relationships shown in Table II, based on circulation patterns during nearly a century in which several major secular changes have taken place, will prove stable. This point was tested by breaking down the 97 years into the so-called 'westerly' epoch (1896–1939) and the 'blocked' epochs before 1896 and after 1939. Considering the principal rules of Table II(e), when $N_d - N_w \geqslant 2$ the summer rainfall distribution turned out to be 12, 1, 0 in the 'westerly' epoch and 11, 4, 3 in the 'blocked' epoch; when $N_d - N_w \leqslant -2$ the distribution was 2, 5, 8 in the 'westerly' epoch and 0, 5, 13 in the 'blocked' epoch. The accuracy of predictions of dry summers was likely to have been somewhat greater in the 'westerly' than in the 'blocked' epochs, whilst predictions of wet summers were probably better

in the 'blocked' than in the 'westerly' epochs. Nevertheless, there does not appear to be any great difference between the distributions in the two epochs. In the 1960s the general standard was well maintained. The three wet summers (1960, 1966 and 1968) and the three dry summers (1961, 1962 and 1967) had spring pre-conditions which satisfied rules (e)3 and (e)1 respectively. Indeed for the decade 1960–69 the high value of 2·6 was achieved for the mean Sutcliffe score. The recent two summers 1970 and 1971 were not considered in deriving the rules. In fact the rules in Table II correctly predicted summer 1970 but not summer 1971. The predictor for a dry summer was satisfied in March 1971. No prediction was possible from the April pressure anomalies, but the May pressure anomaly rule suggested that the summer would be wet. The overall rule based on the three spring months gave $N_d - N_w = 2$ and so the overall predictor for a dry summer was just satisfied. Evidently the circulation in March, April and May was somewhat conflicting, although the overall rule was satisfied. In the event the June to August period of 1971 was wetter than usual (rainfall just above the tercile 3 boundary), largely as a result of a very wet June. Summer 1971 was in fact peculiar. There were other indications that a good summer was likely in 1971, including those mentioned in a statement by Sir Graham Sutton.[5] Moreover, Murray[6] has drawn attention to the fact that it was only the conventional summer (i.e. June to August) that was on the wet side. Indeed any other period of 3, 4 or 5 consecutive months from June to October 1971 was drier than usual.

Forecasting summer temperature. The individual indicators based on monthly mean pressure anomalies are given in Table III.

The positions where the rules of Table III apply are conveniently indicated in Figures 6, 7 and 8.

The individual rules were next combined in the manner employed to derive predictors for summer rainfall. The temperature predictors are summarized in Table IV.

From Table IV it is seen that very useful predictive relationships exist as early as March but on rather less than 50 per cent of occasions. The mean circulation in April can give useful predictions on over 50 per cent of occasions. However, the anomalous mean monthly circulations in key areas in March and April can be combined to produce three predictors which cover virtually all cases (one year is not included since $N_c = N_w = 0$). At the end of April positive predictions can thus be made and the success is likely to be high. If the more stringent criteria given in brackets are required to be satisfied the success of the predictions appears likely to be very high.

The circulation in May is important on less than 45 per cent of occasions. Nevertheless, the inclusion of this month's mean pressure anomaly rules with the predictors available in March and April means that three predictors emerge, as shown in (e) of Table IV. In this case only one year is omitted owing to the fact that $N_c = N_w = 0$. The predictions of cool, average and warm summers based on the criteria laid down in Table IV(e) will give negative Sutcliffe scores (i.e. failures) on just over 12 per cent of occasions. When the more stringent criteria given in brackets are insisted upon then predictions can be made on only 29 occasions (about 30 per cent), but only one was seriously in error (i.e. $SS < 0$) — a remarkable result in the field of

TABLE III—PRESSURE ANOMALIES AND PRESSURE ANOMALY DIFFERENCES AT KEY AREAS IN MARCH, APRIL AND MAY RELATED TO SUMMER MEAN TEMPERATURE IN CENTRAL ENGLAND

Rule No.	Pressure anomaly (PA) or difference	Normal	Critical anomaly	Temperature (quintiles) 1	2	3	4	5
		millibars						
(a) March								
1	PA(30 10E)	1015·7	≥ 2	4	9	2	2	2
2	PA(50 80)	1016·7	> 3	7	5	3	2	0
3	PA(55 170E)	1007·3	< −4	2	1	2	10	6
4	PA(70 80E) −PA(55 170E)	1014·6 − 1007·3	< −1	9	13	8	2	4
5	PA(70 80E) −PA(55 170E)	1014·6 − 1007·3	> 7	2	0	3	7	4
6	PA(45 170)	1011·3	> 6	5	6	4	1	0
(b) April								
7	PA(45 20E)	1013·0	≤ −2	9	5	6	0	2
8	PA(45 20E)	1013·0	> 2	0	1	5	7	4
9	PA(80 60E)	1015·5	< −4	0	1	5	7	3
10	PA(80 60E)	1015·5	> 4	9	2	4	2	1
11	PA(45 20E) −PA(80 60E)	1013·0 − 1015·5	< −5	11	4	3	1	2
12	PA(45 20E) −PA(80 60E)	1013·0 − 1015·5	> 5	1	2	7	6	4
13	PA(40 80E) −PA(80 60E)	1015·2 − 1015·5	< −5	9	2	5	0	3
14	PA(40 80E) −PA(80 60E)	1015·2 − 1015·5	> 4	2	3	5	8	4
15	PA(70 140)	1018·8	> 3	9	2	2	3	1
16	PA(60 50) −PA(70 140)	1009·3 − 1018·8	< −5	7	2	5	2	1
17	PA(60 50) −PA(70 140)	1009·3 − 1018·8	> 3	3	5	7	4	13
18	PA(35 160) −PA(70 140)	1020·9 − 1018·8	< −4	8	4	2	5	0
(c) May								
19	PA(70 120)	1019·6	> 2	9	8	8	6	0
20	PA(60 70)	1014·4	> 3	7	3	3	2	1
21	PA(30 10E) −PA(60 00)	1012·9 − 1014·6	< −4	0	3	6	6	7
22	PA(80 20E)	1018·1	> 4	8	5	1	2	1
23	PA(65 170E)−PA(80 20E)	1013·6 − 1018·1	≤ −5	7	7	1	1	3
24	PA(65 170E)−PA(80 20E)	1013·6 − 1018·1	> 5	1	3	2	6	6

Normal monthly pressure or pressure difference refers to the period 1873 to 1968.

Note : Quintile boundaries, based on period 1874 to 1963, are : $T_1 \leqslant 14{\cdot}5$; $14{\cdot}5 < T_2 \leqslant 15{\cdot}0$; $15{\cdot}0 < T_3 \leqslant 15{\cdot}4$; $15{\cdot}4 < T_4 \leqslant 15{\cdot}7$; $T_5 > 15{\cdot}7$°C.

TABLE IV—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED ON MONTHLY PRESSURE ANOMALIES IN MARCH, APRIL AND MAY OVER THE NORTHERN HEMISPHERE AND SUMMER MEAN TEMPERATURE IN CENTRAL ENGLAND

Period		Predictor $N_c - N_w$	Summer temperature (quintiles) 1	2	3	4	5	Totals	*SS*
(a) March		≥2	9	10	4	0	0	23	2·4
		≤−1	2	0	3	11	7	23	2·0
(b) April		≥2	13	6	3	3	1	26	2·0
		≤−2	1	3	4	10	7	25	1·6
(c) May		≥2	10	7	1	1	1	20	2·4
		≤−1	1	2	5	5	9	22	1·7
(d) March + April		≥2	14	14	4	2	2	36	2·0
		(≥5)	(9)	(3)	(1)	(0)	(0)	(13)	(3·2)
		1	1	0	8	1	2	12	1·7
		<0	2	5	10	14	15	48	1·4
		(≤−2)	(1)	(2)	(3)	(13)	(7)	(26)	(2·0)
(e) March + April + May	1	>3	14	12	2	1	0	29	2·7
		(>6)	(9)	(5)	(0)	(0)	(0)	(14)	(3·2)
	2	1 or 2	3	4	10	3	4	24	1·1
	3	≤0	1	3	10	14	15	43	1·8
		(≤−3)	(1)	(0)	(1)	(8)	(5)	(15)	(2·2)

N_c and N_w are the number of individual rules (Table III) which indicate cool (quintiles 1 or 2) and warm (quintiles 4 or 5) summers respectively. *SS* is the mean Sutcliffe score.

Note : For a predictor value in brackets, the tercile distribution is shown in brackets.

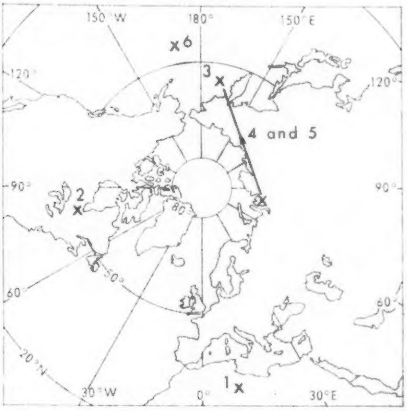

FIGURE 6 — POSITIONS OF SUMMER TEMPERATURE PREDICTORS BASED ON MARCH MEAN PRESSURE ANOMALIES GIVEN IN TABLE III (a)

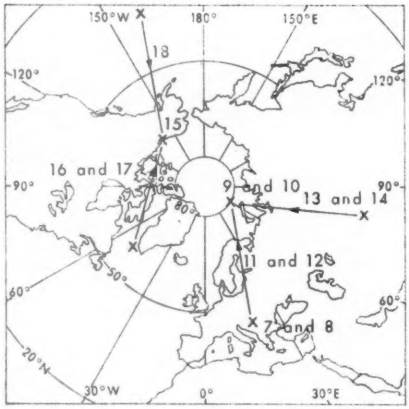

FIGURE 7 — POSITIONS OF SUMMER TEMPERATURE PREDICTORS BASED ON APRIL MEAN PRESSURE ANOMALIES GIVEN IN TABLE III (b)

Positions used in PA differences are joined by arrows.

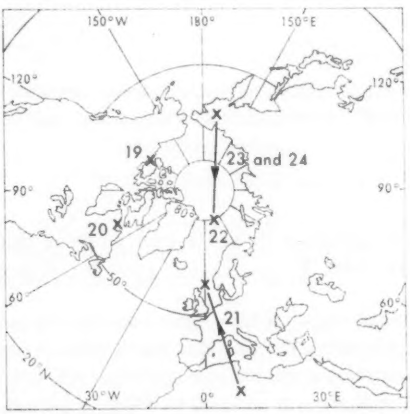

FIGURE 8—POSITIONS OF SUMMER TEMPERATURE PREDICTORS BASED ON MAY MEAN PRESSURE ANOMALIES GIVEN IN TABLE III (c)

Positions used in PA differences are joined by arrows.

seasonal forecasting. The composite summer mean pressure anomaly map for the cases satisfying the criterion $N_c - N_w \geqslant 6$ (Table IV, (e)1) is shown in Figure 9. It is seen that negative pressure anomalies (significant at the 5 per cent level) occur over Scandinavia and in the Gulf of Alaska and significant positive pressure anomalies over central and north Canada and also over Asia centred at about 50°N 100°E. The less restrictive case $N_c - N_w \geqslant 3$ has a summer pressure anomaly pattern similar to but slightly weaker than that shown in Figure 9. The criterion $N_c - N_w \leqslant -3$, associated with warm summers, results in the composite map given in Figure 10 in which the mean pressure is significantly above average from the British Isles to

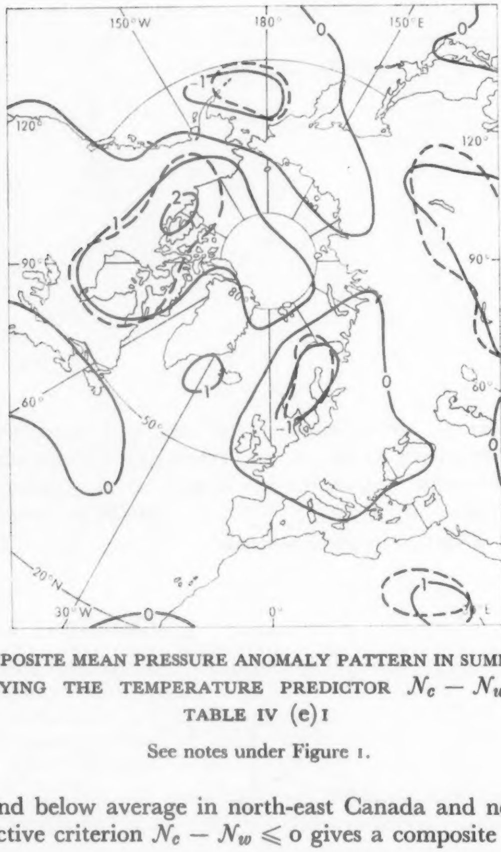

FIGURE 9—COMPOSITE MEAN PRESSURE ANOMALY PATTERN IN SUMMERS FOLLOWING SPRINGS SATISFYING THE TEMPERATURE PREDICTOR $N_c - N_w \geqslant 6$ GIVEN IN TABLE IV (e)1

See notes under Figure 1.

Scandinavia and below average in north-east Canada and north Greenland. The less restrictive criterion $N_c - N_w \leqslant 0$ gives a composite map rather like Figure 10.

The whole period was next subdivided into the 'westerly' and 'blocked' epochs, as was done for rainfall. For the main rule (e)1 of Table IV, when $N_c - N_w \geqslant 3$ the summer temperature distribution was 7, 7, 1, 1, 0 in the 'westerly' epoch and 7, 5, 1, 0, 0 in the 'blocked' epoch; for rule (e)3 when $N_c - N_w \leqslant 0$ the distribution was 0, 2, 5, 4, 7 in the 'westerly' epoch and 1, 1, 5, 10, 8 in the 'blocked' epoch. Again there seems little difference between the distributions in the two epochs.

In the recent decade 1960–69 the summers were generally in accord with the relevant predictors, except 1962. Actually, summer 1962 was fairly unusual in that it was very cool and dry. Although the temperature in summer 1962 was not in agreement with expectations from the predictors, the rainfall was well indicated by the predictive rules, as mentioned in the previous section. Data for summers 1970 and 1971 were not employed in deriving the rules in Table IV. The circulation parameters in spring 1970 correctly indicated a warm summer in 1970. The predictors in spring 1971 also suggested that summer 1971 would be warm (quintile 4 or 5) but in the event the mean temperature for June to August was only quintile 3, mainly because of the very cool June. However, as already mentioned in connection

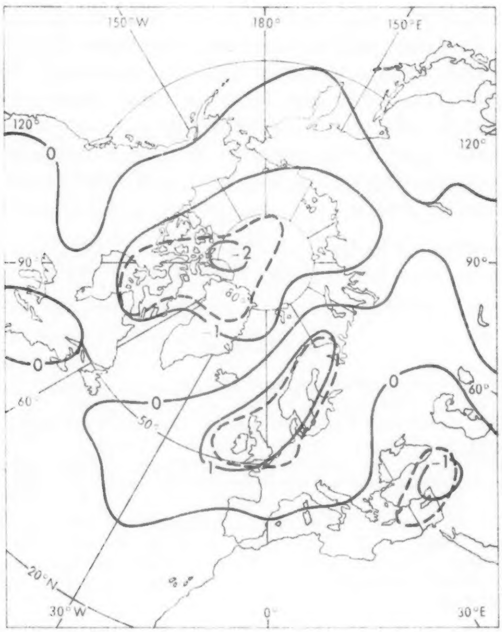

FIGURE 10—COMPOSITE MEAN PRESSURE ANOMALY PATTERN IN SUMMERS FOLLOWING SPRINGS SATISFYING THE TEMPERATURE PREDICTOR $N_c - N_w \leqslant -3$ GIVEN IN TABLE IV (e)3

See notes under Figure 1.

with rainfall in 1971, the summer was unusual. Any period of 3, 4 or 5 consecutive months from June to October 1971 except the conventional summer (June to August) was warmer than usual.

Conclusions. The predictive rules in this paper have been derived from an extensive analysis of monthly mean pressure anomaly data over the northern hemisphere since 1873. The general argument for the use of such data was given in an earlier paper.[1] Briefly, there is a complex interaction between atmospheric circulation and the physical processes operating within and at the lower boundary of the atmosphere (radiation, heat exchange from oceans, etc.). The detailed physical processes cannot be unravelled at present but they seem likely to be traced out in time as a result of highly sophisticated numerical research on the general circulation. Large-scale anomalous circulation, which is linked closely to these physical processes and to the rainfall and temperature which result from their interaction, can be represented to a first approximation by large-scale mean pressure anomalies.

The analysis of the long series of monthly mean pressure anomalies in March, April and May has brought to light several relationships, which are given in Tables II and IV. The main rules at (e) in these two tables can be applied on the great majority of occasions with considerable success. Whenever more stringent criteria are laid down, as indicated in brackets in these two tables, remarkably accurate predictions of summer rainfall and mean

temperature can be made on a smaller number of occasions. It must of course be remembered that the method has been developed for the prediction of seasonal rainfall and temperature over a fairly large area. Predictions for a smaller space-scale (e.g. south-east England) and for a smaller time-scale (e.g. particular weeks or months) within the summer are not attempted. However, the broad procedure outlined in this paper has fairly general applications to regions other than England and Wales and to time-scales other than the summer season.

Acknowledgement. The writer wishes to thank colleagues in the Synoptic Climatology Branch, especially Mr M. J. Weller and Mr P. Collison, for their help in the data processing.

REFERENCES

1. MURRAY, R.; An objective method of foreshadowing winter rainfall and temperature for England and Wales. *Met Mag, London,* **101**, 1972, pp. 97–110.
2. MANLEY, G.; The mean temperature of central England 1698–1952. *Q J R Met Soc, London,* **79**, 1953, pp. 242–261.
3. MURRAY, R.; Some predictive relationships concerning seasonal rainfall over England and Wales and seasonal temperature in central England. *Met Mag, London,* **97**, 1968, pp. 303–310.
4. MURRAY, R.; A note on central England temperatures in quintiles. *Met Mag, London,* **99**, 1970, pp. 292–294.
5. SUTTON, O. G.; Prospects for this summer. *Weather, London,* **26**, 1971, pp. 180–181.
6. MURRAY, R.; A simple summer index with an illustration for summer 1971. *Weather, London,* **27**, 1972, pp. 161–169.

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FORECASTING TEMPERATURE FOR THE GAS AND ELECTRICITY INDUSTRIES*

By G. E. PARREY

Summary. The meteorological requirements of the gas and electricity industries are outlined and the procedure adopted at the Watnall Meteorological Office in forecasting temperatures for the East Midlands Gas Board is described in detail. The accuracy of the temperature forecasts supplied in November and December 1971 is discussed.

Meteorological requirements of the gas and electricity industries. The gas and electricity industries are among the most weather-sensitive industries there are in this country. Both, therefore, require regular weather forecasts so that they can estimate, accurately for up to 24 hours ahead and at least approximately for a further two or three days, what the demand for their product will be. The Central Electricity Generating Board (CEGB) must have the generating capacity available and the area Gas Boards must have the gas, whether manufactured or natural, in the right place at the right time, to meet that demand. In periods of reduced demand, in summer for example, both industries must have quite a high proportion of their plant out of commission for repair and maintenance, and the sudden onset of cold weather must not find them with insufficient equipment at operational readiness.

Each gas and electricity area grid control centre requires from its associated regional forecast office, frequent forecasts of temperature, cloud amount,

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height and thickness, visibility, precipitation, and wind speed and direction. A thick cloud layer and poor visibility, particularly fog, will result in an increased demand for day-time illumination; moderate or heavy precipitation and strong winds give rise to increased demand for heating — as do winds from certain directions; in the Midlands and south-east England, for example, north-easterly winds are said to have a greater chilling effect than winds of the same speed from other directions. But it will be obvious that temperature is the most important factor in determining the demand for both gas and electricity, and it is to the forecasting of temperatures for the grid control centres that this article will be confined.

Requirements for temperature forecasts. At the public service office at Watnall, near Nottingham, the principal forecasts of the day are issued in the early afternoon and the routine which is followed, between 13 and 15 hours (GMT in winter, GMT + 1 in summer) each day, will be described in detail. The office at Watnall is responsible for providing forecasts to the CEGB Grid Control Centres at Birmingham and Nottingham and to the East Midlands Gas Board Grid Control Centre at Leicester. The task which confronts the afternoon forecaster is illustrated in Table I. The CEGB grid

TABLE I—FORECAST TEMPERATURES REQUIRED FOR ISSUE AT 14–15 HOURS

CEGB	East Midlands Gas Board
Mean 06–09 h next day ($D+1$)	Every 2 hours from 17 h on current day (D) until 05 h on $D+2$
09–12	Maximum for current day D and for $D+1$, $D+2$, and $D+3$
. . .	Minimum for $D+1$, $D+2$, $D+3$ and $D+4$
18–21	

controls have a relatively simple requirement for 3-hourly mean temperatures covering most of the following day. On the other hand it will be seen that the Gas Board presents a much more formidable problem; forecast temperatures are required at 2-hourly intervals for the remainder of the current day, D, throughout the next day, $D + 1$, and up to 05 hours on the day after that, $D + 2$. In addition, maximum temperatures are required for the four days D to $D + 3$ and minimum temperatures for $D + 1$ to $D + 4$. The procedure adopted in meeting the requirement of the Gas Board will now be described.

Forecasting maximum and minimum temperatures. The East Midlands Gas Board area includes the heavily populated areas of Sheffield, Nottingham, Derby, Leicester and Northampton; it extends to the Lincolnshire coast to take in Grimsby and Cleethorpes and the boundary follows the Humber to include Goole, Scunthorpe and Doncaster before turning south-west to just north of Sheffield. The forecaster is not required to produce a mean temperature for the whole of that area, or temperatures at more than one place within the area; what he is required to do is to forecast for one reference point — in this case Watnall. Any wide differences expected within the Board's area are merely expressed in general terms, for example : 'three to five degrees colder near the east coast'.

By 13 hours the forecaster has a very good idea what the maximum temperature on the current day will be. His first major problem is, therefore, the minimum temperature during the following night, for the forecasting of which there are a number of well-known methods. The one in common

use at Watnall is based on that due to Craddock and Pritchard[1] who considered data for 16 widely separated stations in England, all of them more than 10 miles (or 15 km) inland. The formula used is :

$$T_{\min} = [0{\cdot}316T_{12} + 0{\cdot}548T_{d_{12}} - 1{\cdot}24] + K,$$

where T_{12} and $T_{d_{12}}$ are the 12 GMT screen dry-bulb and dew-point temperatures (degrees Celsius) respectively, in the air mass which is expected to be over the station during the night. A diagram (Figure 1) can be constructed to give:

$$X = 0{\cdot}316T_{12} + 0{\cdot}548T_{d_{12}} - 1{\cdot}24,$$

where $T_{\min} = X + K$, from T_{12} and $T_{d_{12}}$. The additional correction term K can be obtained from Table II according to the predicted overnight mean cloud amount and mean geostrophic wind speed.

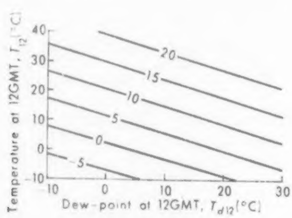

FIGURE 1—DIAGRAM FOR FINDING X IN EQUATION $T_{\min} = X + K$

K is given in Table II.

TABLE II—CORRECTION K TO BE ADDED TO X TO OBTAIN FINAL ESTIMATE OF NIGHT MINIMUM TEMPERATURE

Mean geostrophic wind speed *knots*	Mean cloud amount (oktas) 0 to 2	2+ to 4	4+ to 6	6+ to 8
	degrees Celsius			
0–12	−2	−2	−1	0
13–25	−1	0	+1	+1
26–38	−1	0	+1	+1
39–51	+1	+2	+3	

X is given in Figure 1.

The Craddock and Pritchard method gives good results at Watnall in most circumstances, an exception being when there is an anticyclone centred over the area with clear skies and with no wind overnight. In this situation the method gives values which are generally too high and better results have been obtained by using a formula based on that due to Gold:[2]

$$T_{15} - T_{\min} = 5{\cdot}7 + 0{\cdot}15T_{15} + 0{\cdot}4(T_{15} - T_{d_{15}}),$$

where T_{15} and $T_{d_{15}}$ are the 15 GMT dry-bulb and dew-point temperatures (degrees Celsius) respectively. In this case, as there is likely to be little movement of air mass during the afternoon and following night, the 15 GMT temperatures at the station itself could be used. But as the forecast has to be ready for despatch by 15 hours, it is necessary to estimate the 15 GMT temperature by making a small adjustment to the latest available temperature (14 GMT in winter, 13 GMT in summer).

The next problem is the maximum temperature for the following day. When forecasting maximum temperatures for the current day it is usual to consider a suitable upper-air ascent plotted on a tephigram, make an adjustment to the lower layer for the maximum possible incoming solar radiation at the time of year, assuming clear skies, and then arrive at a forecast maximum temperature by making a further subjective modification according to the cloud amount and thickness, and perhaps also wind speed, expected during the day. This method cannot very well be used for the following and succeeding days and recourse is made to a method based upon an idea by Boyden,[3] who, bearing in mind that the vertical thickness in the atmosphere between the 1000- and 500-millibar levels is one of the easier meteorological quantities to forecast, related this thickness, and the season, to daily mean surface temperature. Later Boyden[4] extended the work to include wind direction and maximum surface temperature. At Watnall the 1000–500-mb thickness, geostrophic wind direction and month of the year have been related to both maximum and minimum surface temperatures. Five years of data (1964–68) have been analysed to give a series of eight diagrams, four in which the 1000–500-mb thickness at midnight is related to minimum temperature and time of year (one diagram for the wind from each of the quadrants north-east, south-east, south-west and north-west), and another four in which the midday 1000–500-mb thickness is related to maximum temperature, time of year and winds from each of the four quadrants. From these it is a simple matter to read off maximum and minimum temperatures for as many days ahead as one has forecasts of 1000–500-mb thickness and surface isobars. A sample diagram is shown in Figure 2. The diagrams have,

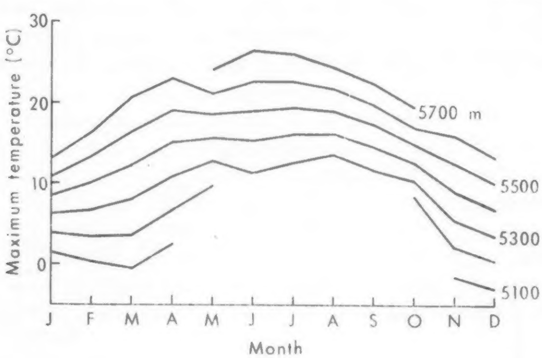

FIGURE 2—MAXIMUM TEMPERATURE RELATED TO 1000–500-mb THICKNESS FOR GEOSTROPHIC WINDS IN THE NORTH-WEST QUADRANT FOR EACH MONTH OF THE YEAR

of course, to be used with some discretion; for example, if the forecast surface chart indicates strong surface winds, one would obviously take a somewhat higher minimum temperature than that indicated on the diagram. As an aid in this respect, monthly extreme values of both maximum and minimum temperatures which occurred with given thicknesses during the five-year period in which data were collected, have been tabulated.

Forecast charts are issued from the Central Forecasting Office (CFO) at Bracknell by about 1230 GMT each day, showing isopleths of the 1000–500-mb thickness values and also the surface isobars and fronts for intervals up to midnight on $D + 3$. Thus, by the methods described, maximum and minimum temperatures can be forecast up to and including the minimum on $D + 3$. This still leaves the maximum on $D + 3$ and the minimum on $D + 4$. To derive these one or other of a number of regression formulae is used. For example :

$$T_{\max(D+3)} = \tfrac{1}{2}(T_{\max(D+2)} + T'_{\max}) ,$$

where $T_{\max(D+2)}$ is the maximum already forecast for $D + 2$ and $T'_{\max}$ is either the 5- or 10-day mean maximum for the station. At Watnall, 10-day means for the period 1941–70 are used. Minimum temperatures can be derived from similar equations, using $T'_{\min}$ as a mean minimum for the station, and proceeding as far as $D + 4$ with the equation :

$$T_{\min(D+4)} = \tfrac{1}{2}(T_{\min(D+3)} + T'_{\min}) .$$

When the situation is particularly difficult, an equation of the type :

$$T_{\max(D+3)} = \tfrac{1}{3}(T_{\max(D+1)} + 2T'_{\max})$$

gives the maximum on $D + 3$ from the maximum temperature forecast for $D + 1$ and the 10-day mean, but in this case with more weight given to the mean.

Forecasting temperatures for 2-hourly intervals. The final task is to forecast temperatures for 2-hourly intervals during the first 38 hours of the forecast period. A useful aid has been found in another series of diagrams which show the mean hourly temperatures at Watnall in each month of the year, constructed from 1961–70 data. Figure 3 shows the curves for January

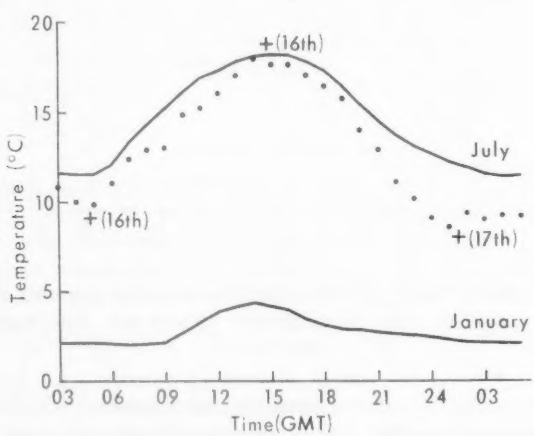

FIGURE 3—HOURLY TEMPERATURES FOR JANUARY AND JULY AT WATNALL

—— Mean hourly temperatures 1961–70
. . . Hourly temperatures from 03 GMT on 16 July 1971 to 05 GMT on 17th
\+ Maximum and minimum temperatures 16–17 July 1971

and July. The curve for the current month is placed behind a transparent sheet and the procedure is to mark the forecast maximum and minimum temperatures for the 38-hour period at the times one expects them to occur and then, using the mean curve as a guide, draw in a forecast curve, bearing in mind such possibilities as the development of convection cloud, shower activity, clearance of cloud in the evening, increase in frontal cloud, or even the passage of a front. The CFO forecast charts give guidance as to the likelihood of any of these occurrences. As an example, Figure 3 also shows the actual hourly temperatures recorded during a period taken at random from July 1971. These follow the shape of the mean curve for July fairly well until 09 GMT when convection cloud first developed and the rise of temperature was temporarily checked. The curve of falling temperature in the late afternoon was almost parallel to the mean until 19 GMT when the cloud dispersed and the fall became much more rapid. Between 01 and 02 GMT a layer of stratocumulus spread over, followed by a slight rise of temperature. It is not of course pretended that *all* these variations can be correctly forecast or even attempted. The three crosses in the figure show the recorded maximum and two minimum temperatures. The fact that they all lie outside the curve of hourly temperatures illustrates the fact that maxima and minima rarely occur precisely on the hour and therefore hourly, or 2-hourly forecast temperatures need not necessarily include the forecast extremes.

The task is now complete, but it remains to be said that although the next full forecast, as described, will not be issued until 24 hours hence, the forecast temperatures are kept constantly under review and are either amended or confirmed in routine messages to the grid control centres at approximately 4-hourly intervals.

Accuracy of forecasts. The programme described has only been in operation for the East Midlands Gas Board since 1 November 1971 and it is too early to make a conclusive assessment of the accuracy of the temperature forecasts made. However, forecasts issued in November and December 1971 have been checked and the results are shown in Tables III and IV. Before it became the practice to issue routine reassessments at 4-hourly intervals, it was a Gas Board (and CEGB) requirement that amendments be issued whenever it was evident that the forecast temperatures were likely to be more than 2 degC in error. It is reasonable, therefore, to regard 'successful' forecasts as those in which the error was within $\pm$ 2 degC. Errors in this range are grouped together in the tables. The few very large errors which occurred

TABLE III—PERCENTAGE FREQUENCY OF VARIOUS RANGES OF ERRORS IN TWO-HOURLY TEMPERATURE FORCASTS FOR D, $D+1$ AND $D+2$, ISSUED BY WATNALL AT 15 HOURS DURING NOVEMBER AND DECEMBER 1971

Error	*D*				*D* + 1												*D* + 2			
	17	19	21	23	01	03	05	07	09	11	13	15	17	19	21	23	01	03	05	hours
degC					*percentage*															
0–2	100	97	87	82	79	70	69	66	73	77	79	79	71	74	71	74	66	61	59	
3		3	11	13	13	18	13	13	10	10	12	10	20	13	18	13	18	18	19	
4			2	3		3	8	11	8	7	5	8	2	10	7	7	8	11	7	
5				2	7	5	7	5	5	3	2	3	6	2	3	2	3	3	8	
6								2	1	2	1		1	1		3		2	2	
7					1	2			3	1	1						2			
8								2							1	1	3	3	2	
9						2	3	1											3	
10																		2		

TABLE IV—PERCENTAGE FREQUENCY OF VARIOUS RANGES OF ERRORS IN MAXIMUM AND MINIMUM TEMPERATURE FORECASTS FOR $D + 1$ TO $D + 4$, ISSUED BY WATNALL AT 15 HOURS DURING NOVEMBER AND DECEMBER 1971

	$D + 1$		$D + 2$						$D + 3$						$D + 4$		
Error	Min.	Max.	Minimum			Maximum			Minimum			Maximum			Minimum		
				M	P		M	P		M	P		M	P		M	P
degC								*percentage*									
0–2	82	84	74	36	51	74	44	49	64	46	57	64	46	46	54	39	48
3	13	8	7	18	17	12	18	18	18	16	5	15	18	16	17	17	10
4	5	2	10	20	15	8	26	8	10	16	3	7	21	10	19	20	10
5		5	2	13	8	3	7	7	3	11	20	6	7	3	3	11	7
6			3	8	3		3	5	2	7	2	3	5	10	2	8	13
7			3	3	3	3	1	5		3	7	5	2	7	3	3	8
8		1	1		2		1	7	3		2		1	3	2		1
9				2	1			1		1	3			5		2	
10											1						3

M Using 10-day means P 'Persistence', using maximum or minimum on day *D*.

were due to such causes as the mistiming of fronts, etc. and would undoubtedly have been corrected in subsequent amending messages. From Table III it will be seen that there is a marked decline in the successful percentage during the early morning of $D + 1$ with a recovery in the afternoon. The cause for this will have to be investigated but as most of the very large errors on $D + 1$ occurred during the early morning, and as Table IV shows that the minimum temperatures on $D + 1$ were quite well forecast, the reason may be the wrong *timing* of the latter due, in turn, to bad timing of fronts, changes in cloud amount, etc.

To illustrate how the forecasts compared with (a) the corresponding mean temperatures and (b) persistence, Table IV also shows the errors which would have resulted if the mean or persistence had been used for maximum and minimum temperatures on $D + 2$ and $D + 3$ and for the minimum on $D + 4$. The 'mean' was taken as the appropriate 10-day mean and for 'persistence' the minimum and maximum temperatures on the day of issue were used.

REFERENCES

1. CRADDOCK, J. M. and PRITCHARD, D.; Forecasting the formation of radiation fog — a preliminary approach. London, Meteorological Office, 1951. (Unpublished, copy available in the Meteorological Office Library, Bracknell.)
2. GOLD, E.; Prediction of minimum temperatures at Larkhill. *Met Mag, London*, **69**, 1934, pp. 88–90.
3. BOYDEN, C. J.; The forecasting of daily mean surface temperature from 1000–500-millibar thickness lines. *Met Mag, London*, **87**, 1958, pp. 98–105.
4. BOYDEN, C. J.; Forecasting of maximum surface temperature from 1000–500-millibar thickness lines. *Met Mag, London*, **91**, 1962, pp. 242–246.

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INVESTIGATION OF A UNITED STATES MIDWEST TORNADO

By E. C. W. GOLDIE and J. M. HEIGHES

Summary. A major tornado outbreak occurred in the United States Midwest on Palm Sunday, 11 April 1965. This outbreak is considered in relation to the aerological situation, and one of the 37 reported tornadoes is selected for investigation. The tornado in question passed within about half a mile of an anemometer, and winds of up to 150 miles/h were recorded. A geometrical method for analysing tornado wind records is discussed, which makes use of the concept of the irrotational vortex. A computerized version of this method was used to analyse the wind record of the Palm Sunday tornado, and useful results were obtained.

Introduction. The United States Midwest is the most tornado-prone region in the world. The highest frequency of tornadoes occurs in Kansas

and Oklahoma; both of these states have one tornado per year per 35-mile square on average. However, the frequency of tornadoes is high from the southern shores of the Great Lakes, down the western side of the Mississippi valley as far as north-east Texas. Every spring tornado outbreaks occur in this region, killing and injuring people, and causing serious property damage.

On Palm Sunday, 11 April 1965, no less than 37 tornadoes were reported over six of the northern states in the United States Midwest. The death toll in these tornadoes was 258, over 3000 people were injured, and property damage was estimated at around 250 million dollars. This was one of the worst tornado disasters ever known anywhere in the world.

Autographic records showing the passage of a tornado are seldom obtained. Wind information is especially valuable, since the manner in which the tornado circulation is formed within the larger circulation of the parent thunderstorm is not well understood at present. Fortunately, two of the Palm Sunday tornadoes passed close to an anemometer without damaging it, and useful records were obtained. The passages of both tornadoes were actually recorded by the same anemometer, which was located near Tecumseh, Michigan (42°N 84°W). The tornadoes passed by the anemometer at 1907 and 2004 CST, respectively (CST is 6 hours behind GMT). The first one resulted in a maximum gust of 150 miles/h* being recorded by the anemometer. This is the tornado which is the subject of the present investigation.

The tornado situation of 11 April 1965. On 11 April 1965, a deep depression moved quickly east-north-eastwards over the Great Lakes region. The depression had a well-marked warm sector, in which warm moist air flowed north-north-eastwards at low levels on the south-east flank of the depression. This warm moist air originated over the Gulf of Mexico on the 9th/10th. A warm front extended eastwards from the depression, with much colder air to the north of it. This front made only slow progress northwards. At the same time, cool dry air was advected rapidly eastwards on the south flank of the depression, behind a dry cold front.

A detailed aerial survey of the damage tracks of the Palm Sunday tornadoes was carried out a few days after the outbreak, and the results were published (Fujita *et alii*[1]). Figure 1 of the present paper is based on Figure 48 of the paper by Fujita. Figure 1 shows the tracks of the storms or storm groups which produced tornadoes. The positions of the storms at hourly intervals (CST) are marked. Continuous lines denote lengths of storm track along which tornadoes occurred. It can be seen that tornadic activity commenced in eastern Iowa at 1230 CST and ended in central Ohio shortly after 23 CST. The positions of Flint, Dayton, Peoria and Green Bay are shown, these being the four upper-air stations nearest to the tornado area.

Figures 2 and 3 show upper-air temperatures and winds, respectively. These are based on the 1800 CST soundings made at Flint and Dayton, using data on microfilm (U.S. Department of Commerce[2]). Wind data were not available for Dayton between 475 and 65 mb, but winds between these levels were estimated in order that Figure 3 could be constructed. Figure 1 shows that an ascent intermediate between those for Flint and Dayton should be representative of the area which was just ahead of the tornadoes at 1800 CST.

* 1 mile/h ≈ 0·45 m/s

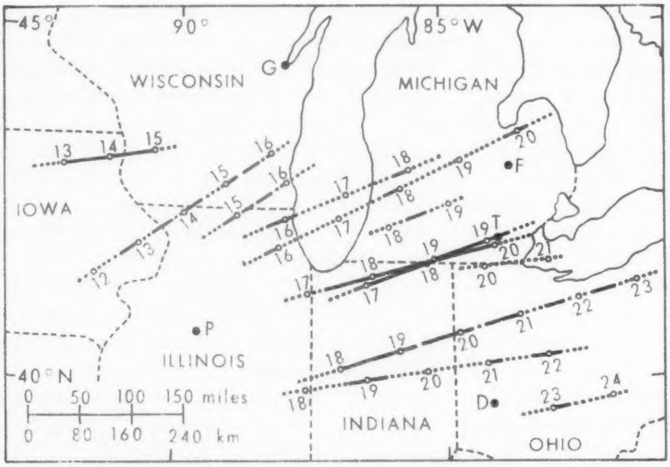

FIGURE 1—TRACKS OF THUNDERSTORMS PRODUCING TORNADOES ON 11 APRIL 1965
(after Fujita *et alii*,[1] Figure 48)

Continuous lines denote occurrence of tornadoes. Positions of storms are at hourly *(CST)* intervals.
F = Flint D = Dayton P = Peoria G = Green Bay T = Tecumseh

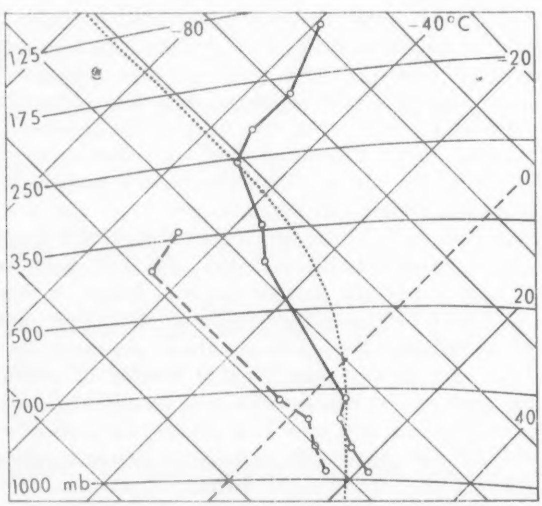

FIGURE 2—TEMPERATURE SOUNDING FOR 18 CST ON 11 APRIL 1965 (MEAN OF FLINT AND DAYTON)

——— Dry-bulb temperature - - - Dew-point temperature
...... Saturated adiabatic for wet-bulb potential temperature = 19°C

The important features to note on Figures 2 and 3 are (a) the warm moist air at low levels, (b) the stable layer near 750 mb, (c) the deep layer of dry air above the stable layer, (d) the steep lapse rate in the moist low-level air,

and in the dry air above the stable layer, (e) the strong vertical wind shear in the lower and middle troposphere, and (f) the marked wind veer with height, especially at lower levels, indicating geostrophic warm advection. The upper-air structure as revealed in Figures 2 and 3 is fairly typical of a severe-storm situation (e.g. Fawbush and Miller[3]).

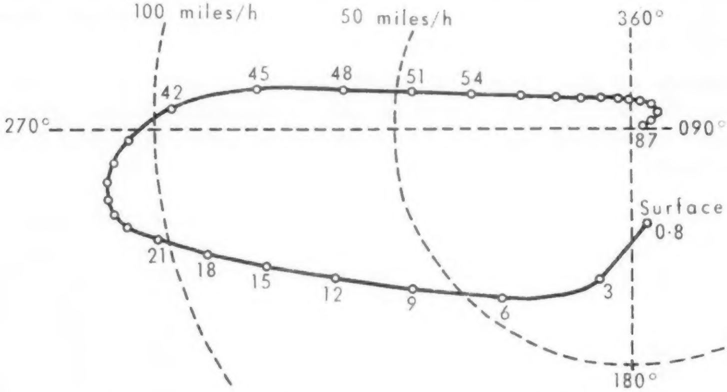

FIGURE 3—UPPER WINDS FOR 18 CST ON 11 APRIL 1965 (MEAN OF FLINT AND DAYTON)

Heights (above MSL) are at intervals of 3000 ft and in thousands of feet.
Based on tabulations by the U.S. Department of Commerce.[2]

All the tornadoes occurred in the warm sector of the depression, just ahead of the dry cold front. Flint and Dayton were both in the warm sector at 1800 CST, while Peoria was in the cool dry air behind the cold front and Green Bay was in the cold moist air to the north of the depression. Tornadoes are a by-product of the intense convective activity which takes place within severe thunderstorms. The upper-air ascent shown in Figure 2 is potentially very unstable, but the stable layer near 750 mb allowed only shallow convection to occur in most of the warm sector. Convective cells penetrated the stable layer west of Flint and Dayton (at 18 CST); this was presumably because of a combination of low-level convergence ahead of the dry cold front and moister air being advected in from the south. In the absence of forced upward motion, the wet-bulb potential temperature of the low-level air would need to be at least 19°C before this air was sufficiently buoyant to penetrate the stable layer. The temperature in the storm updraughts is therefore assumed to have followed the dotted curve shown in Figure 2, i.e. the saturated adiabatic corresponding to a wet-bulb potential temperature of 19°C. Once the stable layer was penetrated, convection proceeded explosively, leading to the development of a number of severe storms. If the temperature curves shown in Figure 2 are correct, they indicate maximum vertical velocities in the storm updraughts of 107 miles/h, and storm tops at 167 mb. In fact, storm tops at 45 000 feet ($\approx$ 150 mb) were actually reported (Weather Bureau Survey Team[4]).

In addition to the exceptional number of tornadoes on Palm Sunday, there were reports of torrential rain, large hailstones, (2·5 cm or more across), intense electrical activity, and severe thunderstorm gusts not associated with

tornadoes. Severe thunderstorm gusts are normally associated with high surface temperatures; day maximum temperatures were around 23°C over most of the area affected by the severe storms. Applying the formula originated by Fawbush and Miller[5], to the upper-air ascent (Figure 2), maximum gusts of 60 miles/h would be predicted. However, gusts of up to 80 miles/h were actually reported (Weather Bureau Survey Team[4]). It should be noted here that the severe storms (and their accompanying tornadoes) advanced at speeds ranging from 40 to 60 miles/h.

Analysis of the Tecumseh wind record. Table I gives wind data covering the period of the first of the two Tecumseh tornadoes. The winds tabulated are derived from the Tecumseh anemometer record, and represent gust averages over a minute, centred on the time given.

TABLE I—ANEMOMETER READINGS AT TECUMSEH ON 11 APRIL 1965

Time	Wind		Time	Wind		Time	Wind	
CST	*deg*	*miles/h*	*CST*	*deg*	*miles/h*	*CST*	*deg*	*miles/h*
1846	150	26	1902	132	54	1910½	231	48
1847	150	22	1903	129	66	1911	228	43
1848	152	24	1903½	133	65	1911½	216	29
1849	148	23	1904	136	73	1912	201	22
1850	138	36	1904½	156	60	1913	202	30
1851	139	33	1905	240	51 (1)	1914	211	20
1852	144	31	1905½	242	78 (2)	1915	227	15
1853	142	38	1906	239	83 (3)	1916	225	15
1854	138	36	1906½	235	67 (4)	1917	225	28
1855	140	38	1907	238	122 (5)	1918	226	19
1856	139	38	1907½	264	149 (6)	1919	245	18
1857	139	40	1908	283	109 (7)	1920	244	22
1858	139	36	1908½	284	89 (8)	1921	257	28
1859	139	47	1909	286	74 (9)	1922	210	26
1900	135	42	1909½	271	64 (10)	1923	199	10
1901	133	41	1910	228	64	1924	202	21

Note : 1 mile/h ≈ 0·45 m/s, Values (1) to (10) were used in the construction of Figure 6.

This wind information is based on that contained in the paper by Fujita.[1] According to Fujita, the tornado travelled in an almost straight line on a bearing towards 073°, its forward speed was 60 miles/h, and at the time of closest approach (given as 1907·4 CST) the centre was 1·2 miles north of the anemometer. Fujita also states that the winds are consistent with an irrotational vortex, i.e. one in which Vr = constant, where V = velocity of air particle relative to tornado and r = radial distance of air particle from centre. The constant for the first Tecumseh tornado is given as 90 miles^2/h, this constant being valid for radii between 0·5 and 2·5 miles.

It is likely that tornadoes in general are approximately irrotational at low levels, in other words the inflow results in angular momentum being conserved. However, this does not apply in the cores of tornadoes, in which solid rotation is believed to occur. Considerable use may be made of the concept of the irrotational vortex in the analysis of tornado wind records. Provided that the tornado is irrotational, is in a steady state, and is travelling in a straight line at a constant speed, it can be proved that if the winds in such a tornado were recorded by an anemometer, the hodograph plot of these winds would trace out a circle which started and finished at the point representing the undisturbed wind. The undisturbed wind in this case refers to the undisturbed wind velocity in the air mass in which the tornado is

assumed to be embedded. It should be emphasized here that for an irrotational tornado, its own forward velocity and that of the undisturbed wind must be assumed to be equal.

Figure 4 shows a plan view of a theoretical tornado track in relation to an anemometer, A. The angle of inflow of the relative winds, ε, is assumed to be constant for any particular tornado. Figure 5 shows the hodograph plot

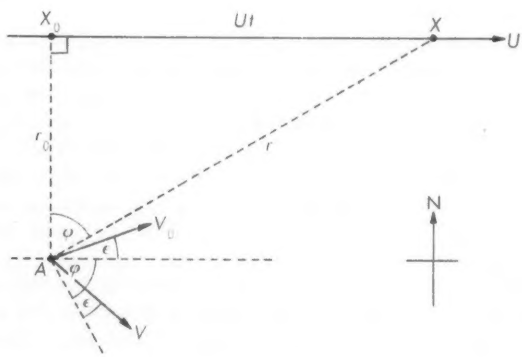

FIGURE 4—PLAN VIEW SHOWING TORNADO TRAVELLING EASTWARDS AT SPEED U ON A TRACK WHICH LIES TO THE NORTH OF AN ANEMOMETER A

X_0 Position of centre at time of closest approach T_0
X Position of centre at time $T_0 + t$

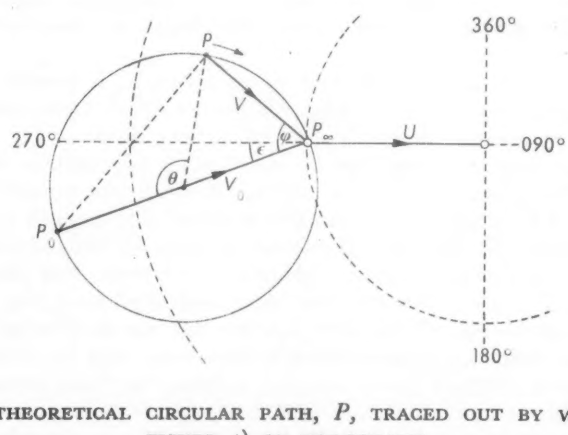

FIGURE 5—THEORETICAL CIRCULAR PATH, P, TRACED OUT BY WINDS (AS IN FIGURE 4) ON HODOGRAPH

The path starts and ends at P_∞. $P_0P_\infty = V_0$ = wind component due to tornado at time T_0. Since $(V\cos\varepsilon)r = (V_0\cos\varepsilon)r_0$ and $r = r_0/\cos\varphi$, $V = V_0\cos\varphi$, and thus the locus of P is a circle of diameter P_0P_∞.

of the winds corresponding to the tornado track depicted in Figure 4. Two very useful relationships emerge from Figures 4 and 5. From Figure 4 it can be seen that

$$\varphi = \tan^{-1}\left(\frac{Ut}{r_0}\right)$$

while from Figure 5 it can be seen that $\theta = 2\varphi$. Note that t is the time interval between closest approach and actual position, and that U and r_0 are constant for any particular tornado.

A casual inspection of the winds (see Table I) suggested that those from 1905 to 1909½ CST inclusive might describe an approximate circle if plotted on a hodograph. These winds were therefore plotted and analysed. The purpose of the analysis was to obtain the best possible fit between the 10 winds as estimated in Table I and their 10 theoretical counterparts, as defined by the relationship $\theta = 2\tan^{-1}(Ut/r_0)$ and thereby obtain values for six constants connected with the tornado, namely α, U, V_0, T_0, r_0 and ε, where α is the direction from which the tornado has come, U is the speed of travel of the tornado, V_0 is the relative wind speed at closest approach, T_0 is the time of closest approach, r_0 is the distance of the centre of the tornado from the anemometer at time T_0, and ε is the angle of inflow of the relative winds.

The analysis was carried out in two stages. The first stage consisted of geometrical construction, from which provisional values for the constants were obtained. The second stage consisted of a computerized version of the first stage; a computer programme was written, by means of which equations based on the geometry of Figures 4 and 5 were solved a large number of times, starting with the provisional values for the constants obtained in the first stage, and using these to obtain a minimum variance between observed and calculated wind velocities at half-minute intervals. The final values obtained for α, U, V_0, T_0, r_0 and ε were 261°, 59 miles/h, 91 miles/h, 1907·43 CST, 0·48 miles and + 4°, respectively. However, it should be emphasized here that the basic data do not really justify the degree of accuracy implied in the above results.

Using the values for the constants given above, it is possible to deduce the theoretical wind at any time. Figure 6 shows a simple method for deducing these winds at specific times. Values of θ were obtained at half-minute intervals from 1905 to 1909½ CST by substituting appropriate values of U, r_0 and t in the equation $\theta = 2\tan^{-1}(Ut/r_0)$ where t is measured from T_0 = 1907·43 CST. The angles θ were marked as radial intersections on the circle, as shown in Figure 6. These radial intersections give the ends of the theoretical wind vectors at specific times at half-minute intervals, and these may be compared directly with the wind data (dots, numbered from 1 to 10). Fairly good overall agreement will be noted between the two sets of winds.

There is one point worth mentioning in connection with the value obtained for α. The value obtained above was 261°, whereas the value given by Fujita[1] was 253°. This value of 253° was obtained from measurements of the track of the storm which gave the first Tecumseh tornado, as recorded on radar film. The damage track of the tornado itself was many miles in length, and measurements of this confirmed the value of 253°, which may therefore be taken as reasonably reliable. A possible explanation for the discrepancy

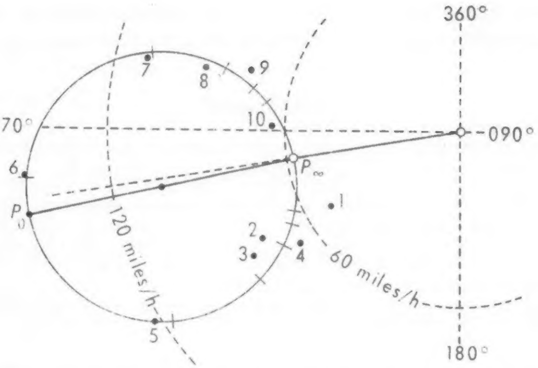

FIGURE 6—CIRCLE OF BEST FIT (AS DEDUCED BY COMPUTER) TO WINDS FROM 1905 TO 1909½ CST

• Values 1 to 10 were obtained from Table I (1) to (10).
Radial intersections give theoretical winds at the same times.

of 8° is that the wind directions recorded by the anemometer were systematically too veered. Had 8° been subtracted from all the directions at the start, this would have resulted in a value for α of 253°.

Finally, it is worth considering the probable position of the tornado in relation to the larger circulation of the parent thunderstorm. Figure 7 shows the winds from Table I plotted with respect to time. It is suggested here that the major direction discontinuity at 1905 CST was caused by the passage of a vigorous gust front. If this is so, it means that the tornado was embedded in the cool outflow air, about 2½ miles behind the gust front. However, at 1907½ CST the tornado was nearing the end of its lifetime, and it seems quite possible that it actually formed slightly ahead of the gust front, and subsequently became engulfed in the cool air without losing its circulation. A temperature discontinuity of perhaps 8 degC existed at the top of the cool

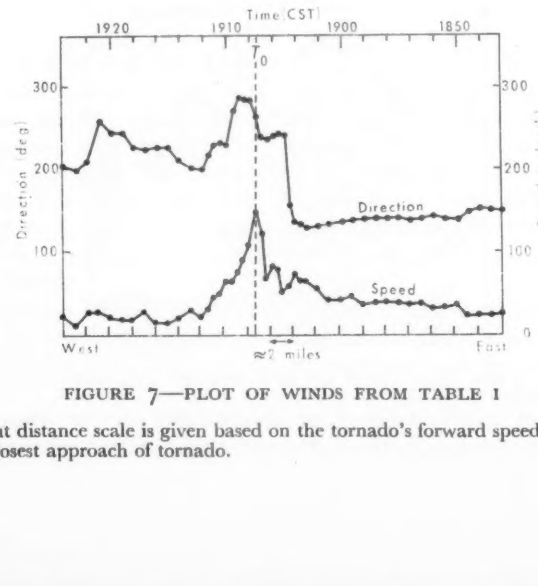

FIGURE 7—PLOT OF WINDS FROM TABLE I

An equivalent distance scale is given based on the tornado's forward speed of 1 mile/minute. T_0 is time of closest approach of tornado.

air, about 3000 feet above the surface; this suggests that in its later stages the tornado circulation may have been limited to the lowest 3000 feet of the atmosphere.

REFERENCES

1. FUJITA, T. T., BRADBURY, D. L. and VAN THULLENAR, C. F.; Palm Sunday tornadoes of April 11, 1965. *Mon Weath Rev, Washington*, **98**, 1970, pp. 29–69.
2. Washington, U.S. Department of Commerce, Weather Bureau. Daily Series, Synoptic Weather Maps, Part II Northern Hemisphere Data Tabulations. Washington, 1965.
3. FAWBUSH, E. J. and MILLER, R. C.; The types of airmasses in which North American tornadoes form. *Bull Amer Met Soc, Lancaster, Pa*, **35**, 1954, pp. 154–165.
4. Washington, U.S. Weather Bureau, Weather Bureau Survey Team. Report of Palm Sunday tornadoes of 1965. Washington, 1965.
5. FAWBUSH, E. J. and MILLER, R. C.; A basis for forecasting peak wind gusts in non-frontal thunderstorms. *Bull Amer Met Soc, Lancaster, Pa*, **35**, 1954, pp. 14–19.

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AN INTERESTING WEATHER PHENOMENON IN AN ICELANDIC FIORD

By R. BOJDYS

The weather reported in this note was experienced by the author when he was the meteorologist aboard M.V. *Miranda*, 1460 tons, the support ship to the British fishing fleet in waters around Iceland.

Description. Stormy weather had persisted in the region of the Denmark Strait for a number of days. On the morning of 30 December 1971 most of the fishing fleet moved to more sheltered fishing grounds to the north and north-east of Iceland, and at 10 GMT *Miranda* took shelter in Dyrafjörður, a long narrow fiord on the north-west coast of Iceland. *Miranda* had experienced moderate to heavy rain continuously since midnight. Dyrafjörður (Figure 1), some 35 km long and 4 km wide, is well sheltered on three sides by ranges

FIGURE 1—MAP OF NORTH-WEST ICELAND

X Position of M.V. *Miranda* in Dyrafjörður on 30 December 1971 Keflavík is about 120 n.miles to south-south-east.

of snow-covered mountains which in parts rise steeply to heights of 600–900 m (2000–3000 ft) within a horizontal distance of 2 km from the shore.

On the sea at the foot of the mountains there appeared long shallow ribbons of white sea spray which looked like fine veils. These ribbons were 7–10 m high; frequently they extended to the height of *Miranda's* bridge. They formed on all three sides of the fiord. Usually their length was between 30 and 100 m, though occasionally one was as long as 200 m. Each veil moved rapidly in a twisted pattern towards the axis of the fiord. Individual recognizable elements lasted for about 10 seconds, often merging with other veils; meanwhile new veils formed almost immediately at the foot of the mountains. None of the veils reached *Miranda*, whose shortest distance to the coast was between 2 and 3 km, but some approached to within an estimated distance of 100 to 50 m before dissipating. It is estimated that visibility inside the veils would be reduced below 100 m.

Comment. At 12 GMT on 30 December 1971 a depression with central pressure 972 mb was centred at 64°N 40°W and the gradient wind over the fiord was 200°, 50 kt. When the veils were observed, surface wind in the fiord was 130°, 45–50 kt with gusts to 90 kt, air temperature was 7°C and sea surface temperature (measured by the bucket method) was 3°C. The tephigram from Keflavík at 00 GMT on 30 December 1971 (Figure 2) showed

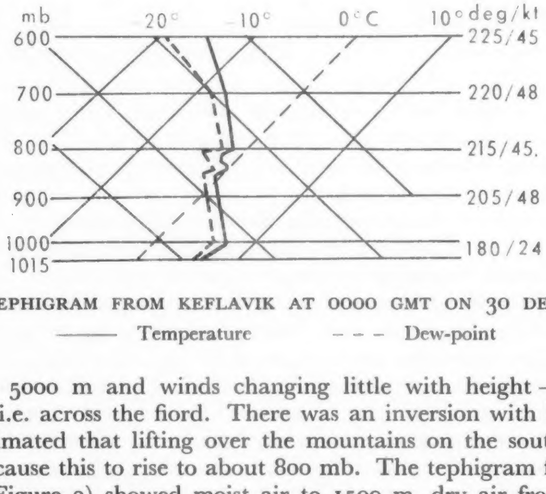

FIGURE 2—TEPHIGRAM FROM KEFLAVIK AT 0000 GMT ON 30 DECEMBER 1971
——— Temperature - - - Dew-point

moist air to 5000 m and winds changing little with height — on average 220°, 45 kt, i.e. across the fiord. There was an inversion with base 865 mb, and it is estimated that lifting over the mountains on the south side of the fiord would cause this to rise to about 800 mb. The tephigram from Keflavík at 12 GMT (Figure 3) showed moist air to 1500 m, dry air from 1500 m to 4000 m, then moist air to 8000 m. Wind structure was similar to that at 00 GMT, the average value being 200°, 55 kt. The inversion with base 865 mb was more marked, and lifting over the mountains would again cause this to rise to about 800 mb.

With an inversion just above the tops of the mountains, the air presumably travels along the length of the fiord as though it is trapped in a tunnel between the mountains, the inversion and the sea surface, and the angle at which the surface wind is inclined to the gradient wind (in this case about 70 degrees) is determined solely by the direction in which the fiord lies. As winds do not increase with height, conditions are not suitable for the formation of lee waves.

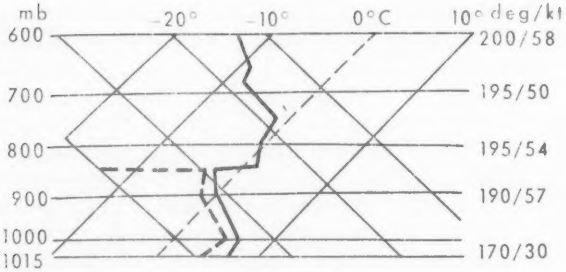

FIGURE 3—TEPHIGRAM FROM KEFLAVIK AT 1200 GMT ON 30 DECEMBER 1971

——— Temperature - - - Dew-point

It may be that turbulent rollers are produced in the fiord with their axes parallel to the mountains and rotating with their undersides moving towards the sides of the fiord. The upcurrents at the sides of the fiord would produce the veils which then move to the middle of the fiord on the top sides of the rollers and dissipate in the downcurrents.

REVIEWS

The changing climate, by H. H. Lamb. 233 mm × 154 mm, pp. xi + 236, *illus.,* Methuen and Co. Ltd, 11 New Fetter Lane, London, EC4, 1972 (Paperback edition). Price: £1·10.

This book is a collection of eight papers by H. H. Lamb which originally appeared in various journals between 1959 and 1964. The collection was first published by Methuen in 1966 and is now reissued virtually without change as a University paperback.

The book is well produced and the diagrams are reasonably clear and the whole will form useful first reading for university and other students. The main criticism must inevitably be that the book is out of date. There can be few scientific fields in which progress has been slow over the last eight years and although there may not have been startling progress in the study of climate, advances have been made in this field too. Since 1966 Lamb himself has published several major works, notably his study of 'Volcanic dust in the atmosphere'[1] and also his major paper on 'Climates and circulation regimes developed over the northern hemisphere during and since the last ice age'.[2]

In 1972 a book on the changing climate should refer to current progress in developing a satisfactory numerical model for use in climate change studies (much work on this subject has been done in America by the Smagorinsky group). The book should also refer to the possibility that man himself has now reached the stage where he may be affecting the global climate by means of carbon dioxide or other effluents, by increasing the dust content of the atmosphere or even by the production of heat in industrial conurbations.

In short the book is concerned almost entirely with climatic history and gives little indication of the pitfalls which threaten extrapolation of past trends into the future. It is hoped that the author will bring out a more complete and up-to-date book, remedying these omissions, in the near future.

R. A. S. RATCLIFFE

REFERENCES

1. LAMB, H. H.; Volcanic dust in the atmosphere; with a chronology and assessment of its meteorological significance. *Philos Trans R Soc, London*, A, **266**, No. 1178, 1970.
2. LAMB, H. H.; Climates and circulation regimes developed over the northern hemisphere during and since the last ice age. *Palaeogeogr, Palaeoclim, Palaeoecol, Amsterdam*, **10**, 1971, pp. 125–162.

Climate: Present, past and future, Volume 1, Fundamentals and climate now, by H. H. Lamb. 255 mm × 195 mm, pp. xxxi + 613, *illus.*, Methuen and Co. Ltd, 11 New Fetter Lane, London, EC4, 1972. Price: £11.

Twenty or so years ago one knew what to expect in a book on climate. Its theme would be the averages of temperature, rainfall, cloudiness and so on, and their seasonal and geographical variations. A rather prosaic but useful recital of facts enlivened by only a limited rather general discussion of the causes of climatic differences from place to place. However, in the last decade climatologists have developed their subject in several directions; synoptic climatology and dynamical climatology have appeared, and with the development of numerical methods of simulating climate by dynamical models we can expect future climatologies of the earth to take a highly mathematical and theoretical approach.

Mr Lamb's book however follows none of these lines. It is a highly personal account of an aspect of weather and climate to which Mr Lamb has devoted much of his interest and study over two decades. It deals with variations of weather on all time-scales from a few days to centuries and millenia. The emphasis throughout is upon the way in which the longer-term climatic variations are built up from the anomalies of weather behaviour over shorter periods. The climatic anomaly of a century, or even an ice-age, is to be thought of not as a change in the average level of temperature, but in terms of the reorientation of the tracks of depressions and anticyclones with all that leads to in terms of changed sequences of weather.

Such a theme provides a fascinating book, full of intriguing facts about past climate and weather: that the earlier explorers of Canada walked over ice on the Great Lakes in June in the early 17th century or that the strength of the north-east trade winds in the Atlantic is correlated with later European temperatures. However, such facts are not easy to explain. Plausible chains of cause and effect can be postulated and Mr Lamb's book contains descriptive accounts of many such. However, until the relationships can be put into quantitative form and tested against numerical data, it is difficult to have any confidence in the significance of the processes to which the climatic effects are attributed. To put the theories of long-term weather variation to the quantitative test will be the task of future generations of dynamical climatologists and Mr Lamb's book will give them much material for investigations.

From the beginning to the end of his book Mr Lamb beguiles the reader with interesting aspects of weather variations. This makes for stimulating reading by the informed meteorologist, but the newcomer to the subject will find a lack of systematic development of climatology as a subject. The book is organized into chapters on radiation, atmospheric motions, the oceans, the water cycle, etc., and is provided with a comprehensive index, but the reader needs a fairly complete understanding of meteorological and climatological principles before embarking even on the early chapters.

The book will stand for a long time as a unique reference work on the subject of long-term weather variations. The access it provides to the literature through its references will be invaluable and not the least value will be in the appendices which collect together miscellaneous, useful, and often elusive information including data on past solar variations and world climate.

J. S. SAWYER

An investigation of heat exchange, International Indian Ocean Expedition Monographs No. 5, by D. J. Portman and E. Ryznar. 283 mm × 225 mm, pp. 78, *illus.*, East–West Center Press, Honolulu, Hawaii, 1971. Price: $7.50.

This is one of the series of meteorological monographs to be prepared in connection with the International Indian Ocean Expedition (IIOE). Both authors are at the University of Michigan and the main purpose of the investigation which they describe was to set up a network of radiation stations and hence to help in determining the heat exchange at the air–sea surface over the Indian Ocean.

Fourteen stations were initially set up on islands and coasts, each being equipped with a pyranometer, a total hemispherical radiometer and a special twin recorder/integrator system designed to operate on a 50-Hz mains supply. Many records were missed because of equipment failures and unreliable electrical power but usable data were obtained from 12 stations, of which 10 were in the western half of the Indian Ocean between 40° and 80°E, extending from Karachi in the north to Fort Dauphin, Madagascar, in the south, the remaining two being Port Blair, Andaman Islands, and Christmas Island. Measurements relate to the period between the setting up of the stations, between March and December 1963, and the end of 1965.

The work is in two parts, the first an introduction giving background information, a description of the instruments used and site details, with photographs, and the second presenting and analysing the data. There are two appendices, one concerning the calculation of precipitable water from radiosonde data, the other presenting the measurements in the form of tables of daily values of solar radiation and total hemispherical radiation.

In analysing the data, daily totals of incident radiation on cloudless days were first determined and curves of the annual variation at 8 stations between 13°N and 25°S are presented. The curves agree quite well with computed curves, based on values for the outer limit of the earth's atmosphere and appropriate values for precipitable water and fractional dust depletion, except for Mahé Island in the Seychelles where the measured values were usually large. Because the Mahé values were also much larger than those for Mombasa which is in about the same latitude, and the differences could not be completely accounted for, the Mahé values were assumed to be in error and were excluded. Otherwise longitudinal variations were small and this is held to justify the presentation of a latitudinal distribution of average daily total incident solar radiation throughout the year, covering latitudes 25°S to 25°N with isolines at intervals of 25 langleys/day. The fact that the values are generally lower than those published by Budyko is partly explained as being due to attenuation by volcanic dust from the Mount Agung, Bali, eruption of March 1963.

Information on observed cloudiness over the Indian Ocean, in the form of maps of average monthly cloud amount in each 5-degree square, is used to

compute the distribution of solar radiation for each month of 1963 and 1964, using an empirical relationship due to Beryland, the results being presented on 24 maps. Values of reflected solar radiation are computed using an empirical relationship between the albedo for a water surface and solar altitude and a linear relationship is found between average diurnal albedo and daily sums of incident solar radiation. Using this result a latitudinal distribution of reflected solar radiation for cloudless days through the year is obtained. Daily sums of atmospheric radiation, obtained from differences between corresponding hemispherical radiometer and pyranometer measurements, ranged from about 720 to 830 ly for cloudless and cloudy conditions, respectively, but because data were insufficient to provide reliable estimates of seasonal and latitudinal variations a representative average value of 790 ly/day is adopted for the Indian Ocean. Using maps of average sea surface temperature for each month of 1963 and 1964 and the Stefan-Boltzmann law, average daily sums of long-wave radiation emitted by the sea surface were computed for each 5-degree square. Hence the distributions of net radiation exchange were computed for each month of 1963 and 1964, and these also are presented on 24 maps. The distributions of areas of high and low values for the same months in both years are similar but actual values in some months are quite different.

Among the assumptions made by the authors are that the effects of roughness and turbidity may be ignored when computing the solar radiation reflected from a sea surface, that the average diurnal albedo for a water surface is independent of cloudiness and that a single value for the atmospheric radiation can be used for all months and seasons. Already mentioned are the assumption that the longitudinal variation in solar radiation is negligible and the rejection of the Mahé measurements for reasons which are not entirely convincing.

A good number of inconsistencies were noted especially in the first part of the book. For example, photographs of the two installations from which no records were obtained are included while photographs for four stations whose records were used are omitted. There are a number of discrepancies between the numbers of cloudless days for which data are listed in Table 3 and the numbers given in the text on p. 16. Also the values in Table 5 are not always in agreement with those indicated in Figure 9 from which they are said to be derived.

The work is well presented and clearly printed and will be of special interest to meteorologists and other scientists who require information about radiation over the Indian Ocean north of 25°S.

H. C. SHELLARD

NOTES AND NEWS

Retirement of Mr R. A. Hamilton, O.B.E., F.R.S.E.

On 7 July 1972 Richard Hamilton retired from the Meteorological Office in which, for the past four years, he held the post of Assistant Director in charge of the High Atmosphere Research Group. His enthusiasm for practical meteorology, preferably outdoors, was evidenced early in his career and before he joined the Meteorological Office. In 1935, having graduated at Oxford, he was researching with Professor Townsend when he had the

opportunity to join the Oxford Expedition to Nordaustlandet (North-east Spitsbergen) as physicist. This was clearly an interesting and challenging experience for in the following year he joined, as Assistant Surveyor, the British Arctic Expedition to North-west Greenland and Ellesmere Island and it was at Thule, not as famous a place then as it is now, that he first met Musse, his wife. Faced now with the responsibilities of married life he entered the Meteorological Office in 1939 only to leave very quickly to join the West African Meteorological Service, working mostly at Lagos. In 1942 he was seconded to the Meteorological Office and finally joined us on returning from Lagos in 1944. A brief spell at Dunstable was followed by about seven years at Prestwick when once more the call of the Arctic proved too strong and he was released in 1952 to become the Chief Scientist to the British North Greenland Expedition and also second in command. He was clearly well suited to this post because of his endearing personality, rugged endurance and powers of leadership, qualities which earned him the Polar Medal and Bar as well as his appointment to the Order of the British Empire. Returning in 1955 he was first at Prestwick and then went to Lerwick where he was a most successful Superintendent until 1966. Two years at Kew Observatory preceded the appointment from which he has just retired. Papers and articles in many journals and a Pelican book *Venture to the Arctic,* testify to his scientific ability, an ability which he habitually tended to underrate.

He will be sorely missed by his colleagues and not least by the younger members for he retains a youthful and energetic approach to life which belies his years. Having very recently recovered from a quite serious operation he continues to play badminton and squash and in the recent Sports Meeting finished a very close second in the veterans 100 metres. We shall miss his fearsome cries in the Scottish dances which he insisted must form a part of the Annual Dinner and Dance. We have no doubt that he will enjoy his retirement in his new home near Edinburgh and wish him and his wife many years of happy activity.

R.F.J.

OBITUARY

It is with regret that we have to record the death of Mr W. E. James, Higher Scientific Officer, Birmingham Airport, on 19 May 1972.

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